LCA Case Studies

Life Cycle Assessment of Lightweight and End-of-Life Scenarios for Generic Compact Class Passenger Vehicles

Wulf-Peter Schmidt[1]*, Elisabeth Dahlqvist[2], Matthias Finkbeiner[3], Stephan Krinke[4], Silvia Lazzari[5], Dirk Oschmann[6], Sophie Pichon[7] and Christian Thiel[6]

[1] Ford-Werke AG, Vehicle Recycling, D-E479/ W03, D-50725 Köln, Germany
[2] Volvo Car Corporation, Dept. 91710, PVÖS 21, SE-405 31 Gothenburg, Sweden
[3] DaimlerChrysler AG, Design-for-Environment, Mercedes Car Group Development, HPC X602, D-71059 Sindelfingen, Germany
[4] Volkswagen AG, Recycling and Life-Cycle Assessment, K-EFUR, D-38436 Wolfsburg, Germany
[5] Centro Ricerche Fiat, Systems for the Environment – Advanced Process Technologies, Strada Torino, 50, I-10043 Orbassano (TO), Italy
[6] Adam Opel AG, ITDC Regulations and Environment, IPC L1-04, D-65423 Rüsselsheim, Germany
[7] Renault, API PDS CHE 5 50, 204 rond point du pont de Sèvres, F-92516 Boulogne Billancourt cedex, France

*Corresponding author (wschmi18@ford.com)

Abstract

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Goal, Scope and Background. The automotive industry has a long history in improving the environmental performance of vehicles – fuel economy and emission improvements, introduction of recycled and renewable materials, etc. The European Union also aims at improving the environmental performance of products by reducing, in particular, waste resulting from End-of-Life Vehicles (ELVs) for example. The European Commission estimates that ELVs contribute to approximately 1% of the total waste in Europe [9]. Other European Union strategies are considering more life cycle aspects, as well as other impacts including resource or climate change. This article is summarizing the results of a European Commission funded project (LIRECAR) that aims at identifying the environmental impacts and relevance for combinations of recycling / recovery and lightweight vehicle design options over the whole life cycle of a vehicle – i.e. manufacturing, use and recycling/recovery. Three, independent and scientific LCA experts reviewed the study according to ISO 14040. From the beginning, representatives of all Life Cycle Stakeholders have been involved (European materials & supplier associations, an environmental Non-Governmental Organization, recycler's association).

Model and System Definition. The study compared 3 sets of theoretical vehicle weight scenarios: 1000 kg reference (material range of today's end-of-life, mid-sized vehicles produced in the early 1990's) and 2 lightweight scenarios for 100 kg and 250 kg less weight based on reference functions (in terms of comfort, safety, etc.) and a vehicle concept. The scenarios are represented by their material range of a broad range of lightweight strategies of most European car manufacturers. In parallel, three End-of-Life (EOL) scenarios are considered: EOL today and two theoretical extreme scenarios (100% recycling, respectively, 100% recovery of shredder residue fractions that are disposed of today). The technical and economical feasibility of the studied scenarios is not taken into consideration (e.g. 100% recycling is not possible).

Results and Discussion. Significant differences between the various, studied weight scenarios were determined in several scenarios for the environmental categories of global warming, ozone depletion, photochemical oxidant creation (summer smog), abiotic resource depletion, and hazardous waste. However, these improvement potentials can be only realized under well defined conditions (e.g. material compositions, specific fuel reduction values and EOL credits) based on case-by-case assessments for improvements over the course of the life cycle.

Looking at the studied scenarios, the relative contribution of the EOL phase represents 5% or less of the total life cycle impact for most selected impact categories and scenarios.

The EOL technology variations studied do not impact significantly the considered environmental impacts. Exceptions include total waste, as long as stockpile goods (overburden, tailings and ore/coal processing residues) and EOL credits are considered.

Conclusions and Recommendations. LIRECAR focuses only on lightweight / recycling, questions whereas other measures (changes in safety or comfort standards, propulsion improvements for CO_2, user behavior) are beyond the scope of the study. The conclusions are also not necessarily transferable to other vehicle concepts. However, for the question of end-of-life options, it can be concluded that LIRECAR cannot support any general recommendation and/or mandatory actions to improve recycling if lightweight is affected. Also, looking at each vehicle, no justification could be found for the general assumption that lightweight and recycling greatly influence the affected environmental dimension (Global Warming Potential or resource depletion and waste, respectively). LIRECAR showed that this general assumption is not true under all analyzed circumstances and not as significant as suggested. Further discussions and product development targets shall not focus on generic targets that define the approach/technology concerned with how to achieve environmental improvement (weight reduction [kg], recycling quota [%]), but on overall life cycle improvement). To enable this case-by-case assessment, exchanges of necessary information with suppliers are especially relevant.

Keywords: Life cycle stakeholder; lightweighting; passenger cars; recycling; significance of differences; vehicles

Introduction

The European Automotive Industry has applied Life Cycle Assessments (LCAs) for a long time [1–6]. The major focus has been to increase the understanding of life cycle implications for different vehicle concepts or design, and technology options. In support, an elaborate set of guidelines for performing automotive LCA were established by a dedicated LCA working group of the European Council for Automotive R & D (EUCAR) [7]. In a next step, the agreed rules have been jointly applied in a EUCAR research project co-financed by the European Commission's research program for 'competitive and sustainable growth'.

This specific screening LCA project looks at 'light and recyclable cars' (LIRECAR) in a generic way, i.e. not one specific vehicle design with its specific processes. It covers important aspects that are still broadly discussed, also on a European level, looking at passenger vehicles [8,9] including in particular CO_2, resource consumption and diminishing landfilling capacities. Amongst others, lightweight design of cars and recycling of End-of-Life vehicles (ELVs) are options for reducing the impacts on the environment. On the one hand, lightweight design for vehicles, which often means the use of light weight materials, is one promising approach to reduce CO_2 emissions and improve conservation of resources by fuel savings in the car-use phase. On the other hand, recycling of ELVs has the intention of reducing resource consumption and reducing wastes. The project aims at an investigation of the interaction between these two targets by using a holistic and generic approach.

However, having in mind the limitations of LCAs, in particular for supporting these kinds of discussions [10], one guiding principle of this project was the involvement of all affected Life Cycle stakeholders from the very beginning. In an advisory group all life cycle stages are virtually represented by stakeholders. This has been seen to be important for the acceptance of the study results [10], as well as for enabling an optimal exploitation of the study conclusions throughout the life cycle; group members included:

- Material & Part Suppliers: Plastics*Europe* (former APME), Eurometaux, European Aluminium Association (EAA), European Association of Automotive Suppliers (CLEPA), International Iron and Steel Institute (IISI), International Magnesium Association (IMA),
- Automotive Manufacturers: Adam Opel AG, Centro Ricerche Fiat S.C.p.A, DaimlerChrysler AG, Ford-Werke AG, Regienov Renault, Volvo Car Corporation, Volkswagen AG,
- Environmental Non-Governmental Organisation (NGO): Friends of the Earth,
- Research: Institute for Prospective Technological Studies, Joint Research Centre, European Commission (JRC IPTS),
- End-of-Life: European Ferrous Recovery and Recycling Federation / European Shredder Group (EFR-ESG).

While the consumers are seen to be the key stakeholders impacting significantly, for example the use phase of a vehicle, it has been decided not to include them (but an environmental NGO) as consumer impacts and acceptance aspects have also been excluded also from the scope of the study.

All interim reports have been presented to the members of the advisory group in four milestone meetings between May 2001 and May 2003. In addition, a deep dive event has been offered for intensive discussions. All feedback from the advisory group members has been evaluated, discussed and considered. The advisory group supported the overall concept, methodology choices, data and results of the LIRECAR study.

It should be noted, that the screening LCA did not have the intention of becoming a detailed analysis of specific vehicle models, as that is very intricate for complex products (as passenger vehicles) and as this is not necessary for the high-level goals of the study. Nevertheless, full accordance with the ISO 14040 series standards has been an important working goal (and achievement) of this project.

1 Goal and Scope Definition

1.1 Approach

The **goal** of the LIRECAR Project is to identify and assess lightweight design and End-of-Life options from a pure environmental point of view on a life cycle basis. The goal of the study implies a comparative assertion of these options. Any other aspects (besides life cycle, lightweight concepts and recycling issues) are out of the goal and scope of the study. In particular, changes in safety or comfort standards, propulsion improvements for CO_2 or user behavior and acceptance are out of the scope. The purpose is not to generate a general LCA/LCI data model but to answer specific questions including:

- What are the environmental impacts of lightweight design options?
- What is the importance of the EOL phase relative to other life cycle phases?
- What are the impacts of End-of-Life technology variation in the overall environmental profile?

Moreover, it is neither intended to provide absolute results nor to model any particular life cycle phase (such as the use phase) nor to improve any particular technical knowledge (material science, recycling technologies, and so on). As a consequence, the results will be displayed in ranges and no comparison between defined vehicles can be performed. The reflected scenarios and their assumptions are summarized in **Table 1**.

In the LIRECAR Project, the system under consideration consists of three different sets of main vehicle scenarios. 1000 kg reference vehicles (material range of today's End-of-Life, midsized vehicles produced in the early 1990's) and 2 lightweight scenarios of 100 kg and 250 kg reduced weight (scenarios called 900 and 750, respectively) based on reference functions (in terms of comfort, safety, etc.) and vehicle concept. The scenarios represent, by their material break-down, a broad variety of theoretical lightweight strategies – in fact up to 7 vehicle concepts are aggregated in the range of one vehicle scenario. The reference vehicle scenario has been set to ELVs (End-of-Life Vehicles) of today (produced in the 1990's) – a time period that serves often also as a reference for the CO_2 discussion. The positive side effect is that the study can be more easily reduced to lightweight questions

Table 1: Vehicle, use phase and EOL scenario main assumptions (italic: name of scenarios)

	Production assumptions			Use phase assumptions		End-of-Life (EOL) assumptions[4]		
	Reference Vehicle (average)	*900kg* Vehicle Scenario	*750kg* Vehicle Scenario	Fuel Reduction Values (FRV)	Emission Standards	*EOL Today*	*Recycling* Scenario	*Recovery* Scenario
Ferrous	70%	34–60%	15–49%	*Basic scenario:* Reference Vehicle 8.1l/100 km (29 miles per gallon); 0,38 l/100 km * 100 kg[6] [7]; Sensitivity Analysis: 0.1 and 0.5 l/100 km * 100 kg (*FRV 0.1; FRV 0.5*)[6]	*Basic scenario:* Emission and fuel standard of 1990's Sensitivity Analysis: Euro4 emission standard and 10 mg instead of 150 mg sulfur per kg fuel (*Low emission limit*)	Primary Steel / Cast Iron		
Aluminum	3%	11–33%	10–40%			Cast Aluminum		
Non-ferrous (w/o Al)	2%	2–4%	3–9%			Primary non-ferrous metals		
Fluids	2%	1–2%	1–3%			Raffination / Recovery / Neutralization		Recovery[2]/ Neutral.
Glass	3%	2–4%	1–4%			None[1]	None[1]	None[1]
Plastics& Textiles	15%	13–23 %	23–32%			None[1]; 50% of tires: ER[2]	Filler (Talc) [3]	Energy Recovery (ER)[2]
Others[5]	5%	2–9%	1– 11%			None[1]	None[1, 3] / Filler (Talc)	None[1]

[1] No EOL treatment, i.e. leaves as elementary flow the system boundaries and is tracked together with other waste streams of the background processes in the indicator 'Total waste'
[2] recovered energy is delivering thermal energy and electricity
[3] in EOL sensitivity analysis, one analysis is performed granting *no EOL credits* for recycling or recovery products. Another one excludes stockpile goods from the total waste category (*no stockpile goods*)
[4] Virgin products are listed that are substituted by the EOL scenarios (Substitution factor 100%). Production scrap leaving the process unit is treated in a general way (metals are recycled in the same way as indicated for the End-of-Life phase, post-industrial plastics are recycled to substitute fillers). Production scrap that does not leave the process unit is treated in a steady-state LCI model
[5] Others include e.g. bitumen, electronic equipment
[6] 0.38 l/100 km * 100 kg or a FRV of 0.38 means that the fuel consumption is reduced by 0.38 l gasoline per 100 km (approx 0.1 US gallon per 0.62 miles) if the weight is reduced by 100 kg (approx 220.5 lb). FRV 0,1 respectively FRV 0.5 is using the values 0.1 respectively 0.5 instead of 0.38

as other features like ABS, catalytic converter, air bags were not installed in compact class vehicles in 1990's.

In parallel, three End-of-Life (EOL) scenarios are considered: EOL today and two theoretical extreme scenarios (recycling and recovery of fractions disposed today). The technical and economical feasibility of these scenarios is not taken into consideration (e.g. 100% recycling is not possible).

The **functional unit** is defined as follows: a European, compact-sized, five-door gasoline vehicle for 5 passengers including a luggage compartment, and all functions of the defined reference scenario with a mileage of 150,000 km over 12 years, complying with the same emission standards.

The **system boundaries** include the whole life cycle from raw material extraction to the final recycling / disposal stage (**Fig. 1**). However, due to the goal of LIRECAR and the complexity of the car as a system [11], everything is outside the system boundaries that is too company and design specific or associated with no significant environmental burden:

- Specific Part production (specific hood or door panel final processing is excluded, however, general part processing as generic sheet processing, injection molding, etc. are included)
- Assembly process (OEM specific, environmentally minor contribution of process itself [4, Fig. 6]; however, the paint shop is included)
- Transport of foreground processes of production, use or EOL (Manufacturer specific, Environmentally minor contribution of process itself [12])
- Specific waste management of production, use or EOL (water, waste treatment of foreground processes) as they are not significant or uncertain (e.g. for the use phase)
- Non-regulated emissions (exemption: SO_2), evaporative emissions as there is no difference between the scenarios and data or tests are uncertain
- Maintenance (uncertainty on data, in particular for lightweight components)
- Vehicle pre-treatment, dismantling, shredder residue separation is excluded due to its minor environmental impact, in particular of the manual processes itself [4, Fig. 9]
- Supplementary materials (uncertainty of data)

Data requirements: All considered processes should be generic ones, e.g. part production is reflected as general processes not including the specific dimensions of the components, etc. In addition, the data sets have to represent an average technology mix of the appropriate time and geographical reference (1990's, Europe) coming as far as possible from public data. The data shall enable a completeness of 95% of the materials used in all vehicle scenarios.

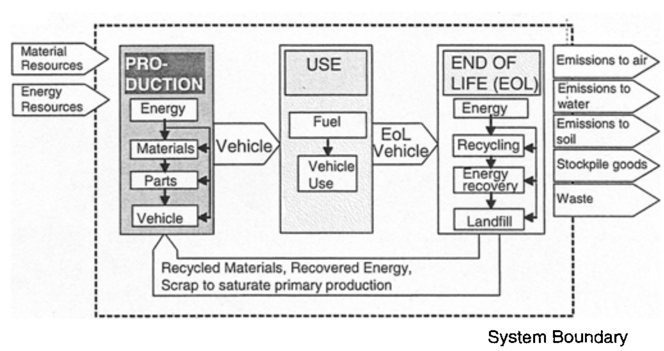

Fig. 1: System boundaries (see Table 2 for processes included in the system boundary)

For the **elementary flows and impact assessment**, LIRECAR is focusing on:

- **Emissions** – Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potentials (POCP) according to CML [13].
- **Waste** – is not an impact category, however, it is shown in terms of total waste and hazardous waste.
- **Resources** – non-renewable resource depletion of energy and materials according to CML approach (ADP).

This study does not include any information on toxicity, effects on biodiversity, landscape degradation, desertification, etc. The rationale is the limited goal of the study. In addition, any reference to these categories would be misleading looking at the completeness of the intended data sources and the system boundaries. There is also a lack of scientifically accepted approaches to cover these issues.

Weighting is not performed, because ISO 14042 [14] explicitly states that weighting cannot be done for comparative assertions disclosed to the public.

A **critical review** panel assured from the beginning to the end of the project that the study is conducted in full accordance with the international ISO standard 14040 Series:

- David Hunkeler, AQUA+TECH Specialties, Switzerland
- Gjalt Huppes, Centre of Environmental Science (CML), Netherlands
- Lars-Gunnar Lindfors, IVL Swedish Environmental Research Institute Ltd. (chairperson), Sweden

1.2 Limitations and rationale for accepting the limitations

Passenger vehicles are very complex products with – depending on the way of counting – up to 180,000 parts. The effort to investigate all elementary flows of a vehicle in detail would be tremendous for even just one vehicle. In this study, it is even necessary to compare several vehicle concepts. This is the reason why also published complete vehicles studies simplify LCIs of single vehicles and do not reflect all vehicle details. Therefore, LIRECAR had to **simplify the detail of investigation**. However, due to the experience of several complete vehicle LCIs, it can be stated that these limitations will not affect the ability to draw conclusions within the goal of this study. But based on this, it is, for example, not possible to:

- Compare existing vehicles with the presented generic vehicles, as features of existing vehicles are highly diverse including various safety and comfort characteristics [15, 5.1.2.4].
- Compare the environmental performance of automotive manufacturing of various companies as the assembly is excluded and general assumptions, e.g. for energy supply, are made.
- Derive conclusions for specific components as general assumptions are done for processing of these parts, e.g. excluding precise design parameters such as thickness, etc.

The **focus in lightweight** due to the link to recycling and due to the reasons provided in this paragraph should be highlighted. To reach the goal of the study, the LCA model has to concentrate on material and recycling issues. The inclusion of other aspects such as increasing customer demand for additional comfort, safety and other functions would partly 'dilute' any effect of lightweight and would not allow clear, comparable and general conclusions anymore regarding the impact of material and weight on CO_2 and recycling goals. Of course, there are various strategies to improve the fuel tailpipe CO_2 emissions including driving behavior (sportive, economic, etc.), aerodynamics, alternative propulsion systems, alternative powertrains, efficiencies of conventional powertrain systems, telematics, etc. Based on this study, no assessment is possible concerning any of these non-material and non-recycling aspects of vehicles. The reasons for focusing on lightweight materials as a strategy to improve fuel economy / CO_2 tailpipe emissions include:

- Besides propulsion/powertrain strategy, lightweight materials are recognized as one important strategy to improve fuel economy. As the focus of this study is on recycling aspects that are affected by recycling technology/ infrastructure and materials in the vehicle, the natural limitation of LIRECAR is to concentrate on materials
- Mainstream market vehicles. EUCAR is expecting that conventional internal combustion engines will continue to be the dominating propulsion system for the next 30 to 50 years [16].
- Not too much design specific. Aerodynamics of vehicles is very much related to the brand-specific way of designing cars and is limited by the acceptance of customers.
- Variety. Driving behavior and available telematic infrastructure will vary significantly between European population and nations.

The LIRECAR study **excludes elementary flows** contributing to environmental impacts that are not of interest to the mentioned European discussion [8,9] and the goal of this study. There cannot be made any conclusion referring to actual impacts of vehicles as all elementary flows can only be assessed according to their (maximal) potential impact.

It has to be noted that – besides the change in material composition and tailpipe emissions – **no prospective data** are covered. In particular, no detailed data for future End-of-life technology or further improvements in the production phase is made. No influence of changed material composition on technology in material production or End-of-life treatment is considered. No incremental / marginal, prospective LCA methods are applied [17]. As far as necessary for the strategic discussions mentioned in the introduction, potential future changes are reflected by the different scenarios or by the sensitivity analysis (see Table 1 for definitions of scenarios).

Despite the limitations of the study, the chosen model and assumptions enable one draw conclusions on the main issues outlined above for the following reasons.

The vehicle scenarios cover a representative range because:

- The chosen vehicle size represents the biggest market share of passenger vehicles on the European market.
- The material composition of the different scenarios represents a broad range of lightweight strategies of most European car manufacturers.

The end of life model can be regarded as representative, because:

- The reference vehicle including its range of different material compositions was produced in the early 1990's and therefore represents the current ELV fleet.
- The different EOL scenarios take into account the options of recycling or energy recovery given by the European directive on ELVs.
- The different EOL scenarios are modeled as extreme scenarios (100% recycling or 100% energy recovery) and therefore represent a maximum estimation for the respective EOL scenario.

2 LCA Results and Interpretation

2.1 Life cycle inventory data model

In the inventory, only data sets have been used that meet the minimum requirement for time-related coverage (not before 1994) (**Table 2**). Most data sets meet the requirement for geographical coverage to use European data (exemptions: material production data from GaBi (mainly Germany) as well as the BUWAL data (Swiss data). With regard to technology coverage, representative average data sets are generally used. In case of individual data sources like that on copper, tire, magnesium or oil recycling these data are not necessarily covering the technology mix. Life Cycle modeling and calculations have been performed by PE Europe GmbH.

Table 2: Data sources of the life cycle model

Data set	Comments	Source
Production Phase		
Steel coils (rolled), steel coils zinc coated (0.75mm), cast iron part (sand casting), stainless steel (steel billet; X12CrNi17 7), aluminum sheet	According to IISI high-strength steel is similar to normal steel sheet.	[18]
Aluminum sheet, cast aluminum (primary ingots, remelting and alloying), aluminum extrusion profiles	Primary/secondary ratio: 50%:50%	[19]
Copper mix (all treated as copper wire; 99.999% electrolyte), lead mix (99.995%)	Only 2% of Pb is primary Pb	[18]
Magnesium AM 60	65% Norsk Hydro, 35% Chinese	[20–22]
PP, HDPE, ABS, PA 6.6, PA 6, PUR, flexible PUR foam, PVC, PET (sc.), PC, PMMA, EPDM rubber, EP	PUR RRIM part (41% Polyol, 36% MDI, 33% glass fibres); rubber assumption according to Plastics*Europe*	[23]
PBT, PPE (PPO), POM, SMC, carbon fibers, glass fibers, textile (PP-, PET-fibers), talcum (Austria), paint (automobile coating), ethylene glycol, sulphuric acid (96%), oil (Lubricating oil free refinery), Bitumen	Coolants assumption: 40% Ethylene glycol / 60% deionised water	[18]
Glass (white packaging), paper (woodfree, coated)	Rough assumption: float glass = 5*packaging glass	[24]
Tires		[25]
Press and body shop (steel + aluminum), paint shop, copper material processing (wires), lead casting, injection molding, cast iron, aluminum casting, magnesium die casting, Metal machining		[18]
Other material processing (paper, bitumen, glass, ceramics) is assumed to be included in material production		none
Use Phase		
Fuels reduction value, average mileage	See Table 1	[26]
Average fuel consumption and regulated air emissions of compact class vehicles in 1990	Referring to average of Astra, Escort, R19, Golf, Tipo in 1990	LIRECAR consortium
SO_2	Calculation based on sulphur content of fuel	
End-of-Life Phase		
Recycling of aluminum		[19]
Steel electric arc furnace		IISI [1]
Recycling of magnesium		IMA [1]
Recycling of lead		Eurometaux [1]
Recycling of oil, cooling liquid, rubber (incl. tires), copper		Specific data
Shredder		EFR
Recycling of thermoplastics (re-granulation + filler substitution), thermosets (shredding + filler substitution); recovery of fluids, waste oil, cooling liquid, break fluids energy, rubber and shredder residue (based on incineration, cement works)		[18]
Rubber landfilling (PP), shredder-residue landfilling, landfilling (mix of landfilling data sets)		[24]

[1] Data input from advisory group members

2.2 Life cycle impact assessment result examples

Within this paper, only a limited number of results can be displayed due to the high number of scenarios (see Table 1 for definitions of scenarios). The result ranges are related to that reference vehicle that has the maximum impact for the specific impact category (please note that the maximum impact for category x is not necessarily related to the same vehicle as for category y). In the figures (**Fig. 2**), the grey part in the bottom of each column stands for the potential environmental impacts of the production phase. Within this grey colored section the part below 0 % represents the credits given for products of the recycling phase. So, the absolute value of both sections in total indicates the potential environmental impacts of the production phase without giving credits for EOL products (no use of recycled materials in production). Looking at the basic scenario with the extreme End-of-Life assumption of recycling for shredder residue (Fig. 2), the positive impact of recycling (credit minus EOL emissions) remains clearly below 10% (often even below 3%) for all impact categories, with few exemptions, while the share of the use phase is mainly 90% or higher for the basic scenario. Only for total waste is the recycling credit the dominant factor, while the use phase share is around 50%. Interestingly, most of these shares are very similar for the other EOL scenarios (no recycling or energy recovery of shredder residue).

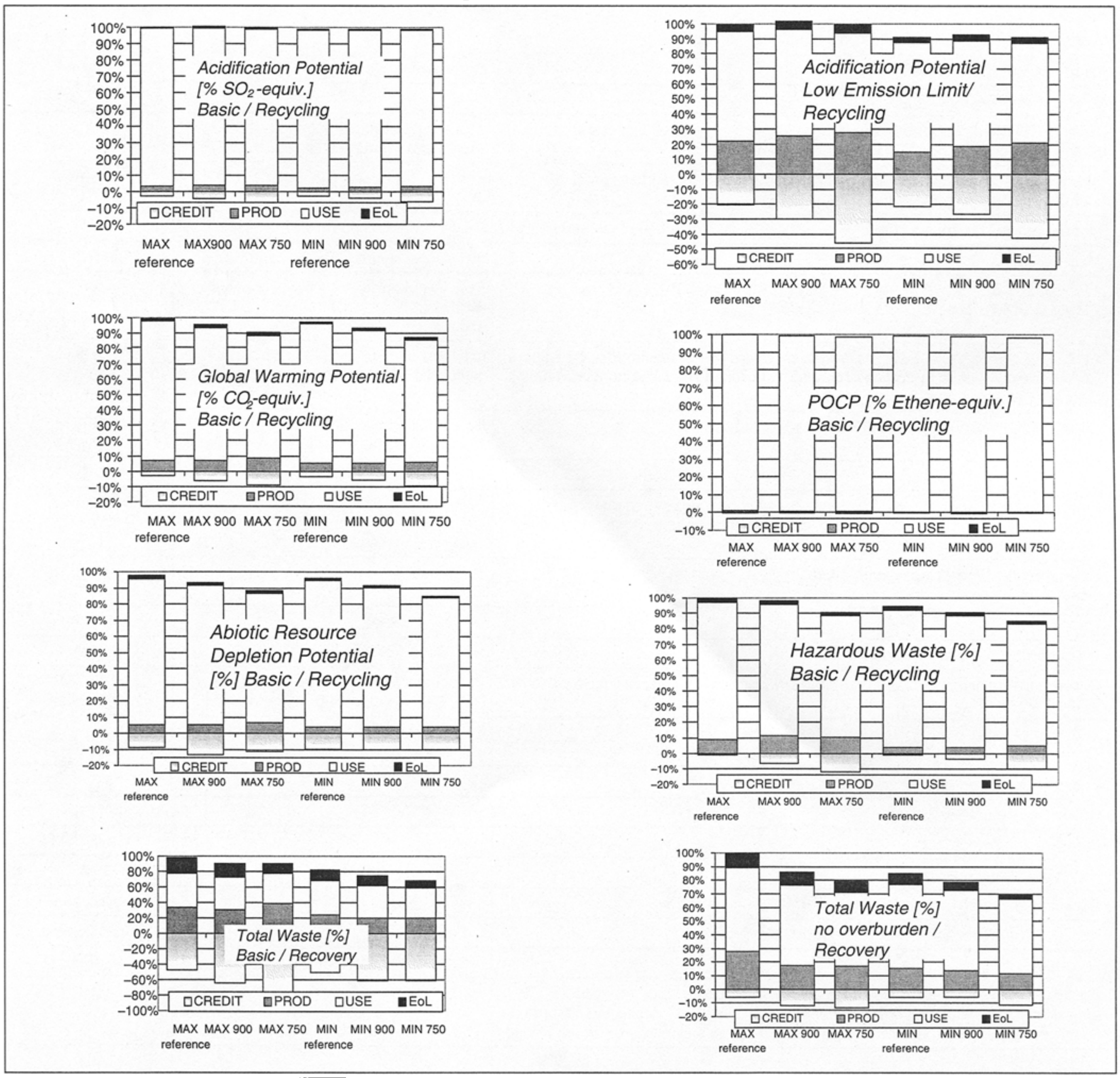

Fig. 2: Shares of different life cycle stages looking at different scenarios (8 examples for scenarios as detailed in Table 1 – other sensitivity results may show different results; minimum or maximum values for different LCIA parameters are not necessarily referring to the same vehicle composition as defined in Table 1; % of max reference)

Significant differences from this general rule include:

- Scenario *Low Emission Limit and low fuel reduction value*: the use phase share gets below 75% for acidification (and eutrophication) potential due to the significantly reduced vehicle tailpipe emissions and the much lower sulphur content in fuels introduced these days. Also the POCP is affected. Same applies for a low fuel reduction value.
- Scenario *No overburden and no credit*: for the category 'total waste', the share of the recycling phase falls clearly under 10%, because most of the total waste comes from overburden. This applies, in particular, to the shredder residue recycling scenario due to the substituted talcum fillers (15.2 kg overburden per kg talcum filler according to the Austrian data set of [18]). Obviously, similar features apply if no recycling credit is provided at all.

Besides the share of different life cycle stages, the total impact relative to the reference vehicle is of particular interest (**Table 6, Appendix**). Again, the range (min – max) is based on the seven vehicle material concepts that lead to a 1000, 900 or 750 kg vehicle, respectively. Thus, the table can be read for example as follows (see bold figures in **Table 6, Appendix**): For the basic scenario, the studied 25% weight reduction concepts result in a reduction for the global warming potential of 9 to 12% if we assume no recycling of the shredder residue (see bold figures 88 to 91%) respectively 9 to 13% if there is full recycling of the shredder residue (and full credits) or 8 to 11% if the recovery (see bold figures 89 to 92%) of shredder residues is assumed. The ranges depend again on the chosen material concept.

2.3 Interpretation of results

Prior to interpretation of the different scenarios, a completeness check and data quality assessment has been performed including:

- Confirmation that the applied data sets met the requirements as defined in the goal and scope definition (exemptions: the geographical coverage and representativeness of data mentioned in section 2.1 – these data have either a small influence or are checked in the sensitivity scenario – see 'no overburden' scenario reflecting the data issue for talcum).
- Confirmation that the most emission and waste elementary flows are covered equally for all processes (exemptions: tailings and sludge from oil exploration is not covered for all plastics).

A major challenge of most LCA studies is to condense all available data without getting non-transparent for the individual scenarios and impact categories. Here, the objective is to determine whether the lightweight or End-of-Life technology variations are relevant for the different environmental categories. This should be only concluded where a significant difference between lightweight or End-of-Life scenarios can be found.

Therefore, the question concerning which differences in the results of the lightweight and End-of-Life scenarios are actually significant has to be addressed considering relevant scenarios altering key assumptions (see Table 1 for the definition of changed key data). This is fairly difficult as there are no established statistical methods to systematically determine the significance of LCA results. As a consequence, other approaches to determine significance have to be applied. Within LIRECAR, two different criteria for a significant difference are applied – the criterion 'No overlap' between the ranges of the material scenarios and the stricter criterion 'Difference larger than material range'.

For the basic scenario, as well as the sensitivity scenarios 'low emission levels' (assuming Euro IV and low sulphur content in fuel), variations of the fuel reduction value ('FRV0.5', 'FRV0.1'), deletion of any recycling credit ('no credit') and the exclusion of overburden for the impact category total waste ('no overburden'), the following checks have been performed:

- Are the ranges for the lightweight scenarios (assuming same EOL technologies) overlapping? If there is no overlap between the reference vehicle and the 900 kg vehicle as well as between the 900 kg vehicle and the 750 kg vehicle, a '++' is assigned. If there is just a 'no overlap' between two of the three weight scenarios, a '+' is noted. However, if the ranges of the different vehicles are overlapping, a '0' is assigned. Looking at the basic scenario example of the figures in italics in **Table 6** (**Appendix**) (98 to 100% for GWP of the reference vehicle, 93 to 96% for the 900 kg vehicle concepts and 88 to 91% for the 750 kg vehicle concepts), all ranges are not overlapping, i.e. a '++' is assigned (see white embossed "++" for the Basic scenario / GWP / lightweight in **Table 3**).
- Are the ranges for the different EOL technologies overlapping for one weight scenario? If there is no overlap between the 'EOL Today' scenario and the 'Recycling' scenario and the 'Recovery' scenario, a '++' is assigned. If there is just a 'no overlap' between two of these, a '+' is noted. If the ranges are overlapping, a '0' is noted. For the basic scenario example of the bold figures in **Table 6** (**Appendix**), all ranges are clearly overlapping, i.e. a '0' is included in Table 3 (see bold '0' in Table 3 for the Basic scenario / GWP / EOL).

If the uncertainties, modeling simplifications, and data uncertainties are seen as more severe (see also section 2.2), the second, stricter criterion applies. The 'difference larger than material range' criterion demands that the difference between, for example, the maximum value of the assumed better scenario A and the minimum value of scenario B is bigger than the result variations of these two scenarios. Again, all scenarios are checked looking now at the following aspects:

- Is the difference between the minimum value of one weight scenario and another weight scenario larger than the largest range between the minimum and maximum value of one of the vehicle scenarios? Looking at the example of the basic scenario figures for global warming in **Table 6** (**Appendix**), the material differences are responsible for a range of 3% units for the reference ve-

Table 3: Significant differences between the scenarios applying the criterion 'No overlap'

Scenario		AP	EP	GWP	ODP	POCP	ADP	Haz. W	Total W
Basic	Lightweight	0	0	++	++	+	++	+	0
	EOL	0	0	0	0	0	0	0	+
Low emissions limit	Lightweight	0	0	++	++	+	++	+	0
	EOL	0	0	0	0	0	0	0	+
FRV 0.5	Lightweight	0	0	++	++	++	++	+	0
	EOL	0	0	0	0	0	0	0	+
FRV 0.1	Lightweight	0	0	0	++	0	0	0	0
	EOL	0	0	0	0	0	0	0	+
No EOL credit	Lightweight	0	0	0	+	+	+	0	0
	EOL	0	0	0	0	0	0	0	0
No stockpile goods	Lightweight	0	0	++	++	+	++	+	0[1]
	EOL	0	0	0	0	0	0	0	0[1]

Criterion: 'No overlap'. A '+' in terms of 'No overlap' means that the minimum value of one vehicle weight or EOL scenario is higher than the maximum value of another weight or EOL scenario
General Note: The lines 'lightweight' and 'EOL' indicate the differences between different lightweight scenarios (with the EOL treatment being the same) or different EOL treatments (with the vehicle scenario being the same)
[1] This result refers to 'Waste to be landfilled/treated' instead of 'Total waste'

hicles, 2–3% units for the 900 kg vehicles and 3–4% units for the 750 kg vehicle. The difference between the minimum global warming potential of the reference vehicles and the maximum for the 900 kg vehicle is just 1% unit (97% vs. 98% for the recovery assumption). However, if a bigger weight difference occurs (reference vehicle vs. 750 kg) then the difference between the minimum global warming potential of the reference vehicle and the maximum for the 750 kg vehicle is big enough (even for all EOL variations: 98% vs. 91%, 97% vs. 91%, 92% vs. 98% – see **Table 6, Appendix**), i.e. bigger than the material range of 4% units. Therefore, one '+' is noted for the Basic scenario / GWP / lightweight in **Table 4**),

- Is the difference between the minimum value of one end-of-life (EOL) scenario and another EOL scenario larger than the largest range between the minimum and maximum value of one of the EOL scenarios? Obviously the answer is 'no' as there is already no significant difference according to the 'no overlap scenario' for all impact categories besides the inventory category total waste. There, the only not-overlapping ranges (recovery vs. recycling for the 750 kg vehicle) have a difference of 7% units, while the scenario ranges are 20% for recycling respectively 23% units for energy recovery. Therefore, there is no significant difference between the EOL variations for any of the scenarios.

Table 4: Significant differences between the scenarios applying the criterion 'No overlap and difference larger than the material range'

Scenario		AP	EP	GWP	ODP	POCP	ADP	Haz. W	Total W
Basic	Lightweight	0	0	+	++	0	+	0	0
	EOL	0	0	0	0	0	0	0	0
Low emissions limit	Lightweight	0	0	+	++	0	+	0	0
	EOL	0	0	0	0	0	0	0	0
FRV 0.5	Lightweight	0	0	++	++	+	+	0	0
	EOL	0	0	0	0	0	0	0	0
FRV 0.1	Lightweight	0	0	0	0	0	0	0	0
	EOL	0	0	0	0	0	0	0	0
No EOL credit	Lightweight	0	0	0	0	0	0	0	0
	EOL	0	0	0	0	0	0	0	0
No stockpile goods	Lightweight	0	0	+	++	0	+	0	0[1]
	EOL	0	0	0	0	0	0	0	0[1]

Criterion: 'Difference larger than material range'. A '+' means that the difference between the minimum value of one weight or EOL scenario and another weight or EOL scenario is larger than the largest range between the minimum and maximum value of one of the vehicle or EOL scenarios
General Note: The lines 'lightweight' and 'EOL' indicate the differences between different lightweight scenarios (with the EOL treatment being the same) or different EOL treatments (with the vehicle scenario being the same)
[1] This result refers to "Waste to be landfilled/treated" instead of 'Total waste'

2.4 Conclusions

Looking at the three main questions, the following conclusions can be drawn:

1. What are the environmental impacts of lightweight design options?

According to the LIRECAR study, with its limitations as described in section 2.2, a significant difference between the different weight scenarios can be identified for GWP, ODP, POCP, ADP and hazardous waste, except for scenarios with a fuel reduction value of 0.1 or if no EOL credit is given. This is still true (only for a theoretical 250 kg weight reduction) for GWP, ODP and ADP when applying the strict criteria 'Difference larger than material range'. The reason for the different results of the FRV 0.1 is that a fuel reduction value of 0.1 l per 100 km and per 100 kg weight savings leads to a significantly smaller decrease in the fuel consumption and related emissions. Therefore, the benefit of the lightweight design is no longer enough to cover the larger environmental impacts of the production phase. The same is true for the no EOL credit scenario. Because there are no benefits (credits) for the recycling products, the potentially higher environmental impacts of the production phase (lightweight materials) are not lowered down. For environmental interventions like AP, EP and total waste there is no significant difference between the reference and the lightweight vehicle scenarios. This shows that the quite substantial and technologically and economically challenging weight reductions assumed in the 750 kg scenarios leads to moderate or even lacking improvements in some impact categories. In addition, these improvement potentials can be only realized under well-defined conditions (e.g. material compositions with regard to specific fuel reduction value and EOL credits) based on case-by-case assessments for improvements along the life cycle.

2. What is the relative importance of the EOL phase?

Looking at the studied scenarios, the relative contribution of the EOL phase is 5% or less of the total life cycle impact for most impact categories and scenarios, if the credits are not allocated to the EOL Phase. Exceptions include scenarios '900 kg vehicle, low emissions' where the EOL phase has an EP share of up to 9% or up to 7% for AP, respectively, as well as the impact category of total waste (EOL share of 9% to 40%).

3. What are the impacts of End of Life technology variation in the overall environmental profile?

Comparing the studied EOL scenarios landfill, recycling and energy recovery, there is no significant difference for the impact categories AP, EP, GWP, ODP, POCP, ADP and hazardous waste. This implies that the intended positive impact of ELV recycling on resource depletion (see section 1) cannot be proven in the study. The only significant difference is for total waste, where the studied recycling scenario leads to an improvement between 25% and 50%. Looking at the dominating, contributing processes to total waste, improvement potentials based on the studied model are linked to power generation (coal as part of power mix) and the ore mining, but not to the actual End-of-Life vehicle treatment itself. If the no EOL credit scenario or the strict criterion 'Difference larger than material range' is applied, the improvement potential of the recycling scenario is no longer significant. If overburden, tailings and ore/coal processing residues (scenario 'no stockpile goods') are not accounted for as total waste, the studied EOL scenarios have no significant effect on the total waste going to further waste treatment or landfilling.

The studied EOL technology variations do not significantly impact the environmental impacts considered. Exceptions include total waste as long as stockpile goods or EOL credits are considered.

2.5 Critical review and stakeholder comments

The critical review panel (see section 2.1) concluded that this screening type of LCA study has an overall quality of the methodology and its execution that is sufficient for the purpose of the study. The Panel found the conclusions balanced and supported by the study. The study has been carried out in a manner consistent with ISO 14040 and other related standards, principally ISO 14041 and ISO 14043. The study did only, as was stated in the goal definition document, provide results on a relative scale, and then restricted to a few, although primary aspects of the vehicle life cycle. The study was still found to be in full accordance with the ISO 14040 series standards, as all these limitations were clearly reported and all conclusions were strictly in compliance with these limitations.

The represented life cycle stakeholder (see section 1) agreed with the overall conclusions while providing some additional views. Plastics*Europe* is suggesting that the positive environmental effects of lightweight options would generally not be dependent on the chosen individual material – looking at the complete vehicle. Friends of the Earth agrees with the LIRECAR findings, but stresses that further conclusions about a recycling / lightweight conflict would be over-simplistic as secondary effects would have to be taken into consideration (e.g. down-sizing, consumer behavior, etc.). IPTS, on the other hand, is seeing an obvious dilemma between CO_2 emission and waste reductions, while also not agreeing with the view of Plastics*Europe*, but arguing that the type of lightweight materials is responsible for some ranges in the results. IISI suggest that all life cycle stakeholders should start improving their own contribution to the overall life cycle impact and establish a dialogue along the life cycle. IISI feels that, on a general, political level, LCAs are not feasible to answer more detailed questions.

3 Studies Covering Similar Questions and Recommendations

The conflict discussed above by the stakeholder group between CO_2 emission and waste reductions has been addressed by different studies. This discussion can be reflected by the following example for the recycling quote of two cars:

If a reference vehicle (1,000 kg) has a material composition where 85% is going to recycling processes then looking at a

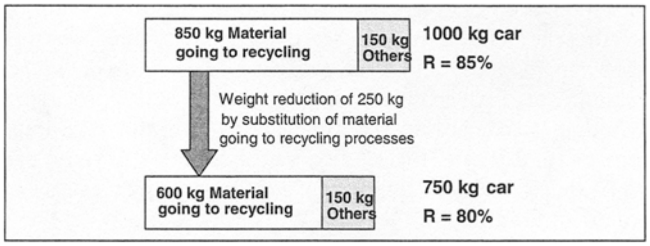

Fig. 3: Trade-off between ELV directive recycling targets (R) and lightweight design options

lightweight vehicle (750 kg), where a weight reduction of 250 kg is achieved by the substitution of materials that are typically going to recycling processes, one can see that the recycling rate drops down to 80%. This shows the trade-off between the recycling targets given by the ELV-directive (2000/53/EC) and the lightweight design options (**Fig.e 3**).

This general conflict between weight-related recycling quotas and lightweighting is detailed also in other papers (see for example [27]). **Table 5** provides an overview on different Life Cycle-related studies that can be used to answer the three key questions that are to be answered by the LIRECAR project.

These different studies show that the main findings of LIRECAR are mainly in line with some of the previous studies:

1. For lightweighting, several studies show positive impacts – however, as indicated in particular by [34], there might be lightweighting material applications that have even negative impacts. Therefore, the LIRECAR recommendation of a case-by-case assessment seems to be reasonable.
2. The low EOL phase importance is agreed upon by all studies which consider the complete life cycle.
3. For the impact of EOL technology variations, one study [32] suggests an impact, i.e. a negative impact of material recycling compared to a specific feedstock recycling. Other studies have not studied this specific feedstock recycling, but have a more generic and complete life cycle perspective.

In contrast to other studies, LIRECAR achieved:

- Comprehensive simplified LCA evaluation of different lightweight AND recycling options on a complete vehicle level
- Life Cycle Stakeholder involvement from the beginning

Table 5: Comparison of answers for the three LIRECAR questions based on different studies

Life Cycle Study	1. What are the environmental impacts of lightweight design options?	2. What is the relative importance of the EOL to other phases?	3. What are the impacts of End of Life technology variation on the overall environmental profile?
LIRECAR study – European, generic whole vehicle study with different weight and EOL variations for shredder residue	Significant impacts in particular for GWP, ODP, ADP – but case-by-case assessment necessary	5% or less for most scenarios	The studied EOL technology variations do not significantly impact the environmental impacts considered – possible significant impact could only be identified regarding stockpile goods
Whole vehicle study for the Netherlands, current Dutch EOL system [28]	Not studied, but pointing to references that suggest importance of improving the use phase and thus the weight of vehicles	"The EOL phase shows a negligible burden and a small benefit"	Low as stating "Purely weight-based recovery definitions are not adequate ... even for countries with advanced collection and recycling"
Review of 9 different whole vehicle LCI studies [29]	Energy consumption and CO_2 emissions correlate with the vehicle weight (while powertrain efficiency impacts the size of correlation). However, SO_2 is linked more to certain lightweight materials than to the total weight	Relatively low	Not studied
7 vehicle plastic parts for ELVs [30]	Not studied, but mentions that lightweight design shall have higher priority if recycling is going to compromise lightweight options	Low – A key indicator as energy consumption is dominated by the use phase	In most cases, no significant difference between recycling & recovery technologies. Significant differences only for 2 large, mono-material parts
4 vehicle plastic parts for ELVs [31]	An application of recycled materials leading to higher weight results, in particular in higher GWP results	Relatively low	There is no recycling or recovery technology that is best for all parts – case-by-case evaluation necessary
Mechanical or feedstock recycling of the shredder residue [32]	Not studied	Not studied	Mechanical recycling is worse than the studied feedstock recycling technologies for GWP, EP, POCP, AP. Only looking at a best-case assumption, mechanical recycling could be slightly superior for EP
Specific automotive parts comparing different material / weight options [33]	Certain lightweight materials can have both positive or negative impacts on the environment depending on part, vehicle, use phase parameters, impact category etc.	For different environmental aspects, the relevance of LC stages is highly variable. The EOL phase, however, is usually below 8%	Not reported
Ultralight vehicles based on carbon reinforced materials (CFRP) [34]	Carbon fiber based lightweighting increases GWP under certain conditions	Not reported	3R technologies are 'indispensable' for CFRP – but no preference is given for a certain technology
Summary of all	Often impact for GWP and energy, but a case-by-case assessment is necessary – in particular where certain lightweight materials are used	Low impact	No difference on complete vehicle level but specific technologies (e.g. specific feedstock recycling technologies) might make a difference if just the EOL phase is compared

Based on the LIRECAR and other studies, the following recommendations can be made:

- Both approaches (lightweight design / End-of-Life treatment) do not seem to have a positive contribution under all circumstances. As a consequence, automotive manufacturers should not be demanded to meet general targets that define the approach/technology concerning how to achieve an environmental improvement (weight target [kg], recycling quota [%]). While difficult to calculate, the overall life cycle improvement is more important than how this can be achieved. This requires individual performance specifications. One example is the potentially increased contribution of the production phase when moving to lightweight design that counteracts achieved improvements of the use phase.
- As the environmental impacts of the EOL phase are rather small compared to the overall life cycle burdens and the improvement potential is therefore very limited, there is no reasonable justification to limit lightweight opportunities and possible improvements in other life cycle phases only for the fulfillment of any EOL quotas or requirements.
- The LIRECAR advisory group consultation showed that the dialogue between the life cycle stakeholders is very important. In order to ensure that automotive manufacturers can make the necessary assessments on a case-by-case basis, exchanges of necessary information with suppliers are especially relevant.

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Appendix

Table 6: Impact Assessment results for the basic scenario, the low emission limit and high fuel reduction value scenarios (% of Reference vehicle, EOL Today)

Scenario		AP		EP		GWP		ODP		POCP		ADP		Haz. Waste		Total W	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
BASIC	RV, EOL Today	99%	100%	98%	100%	*98%*	*100%*	99%	100%	99%	100%	97%	100%	95%	100%	84%	100%
	900 kg , EOL Today	99%	100%	98%	101%	*93%*	*96%*	95%	95%	99%	99%	93%	96%	91%	98%	77%	93%
	750 kg , EOL Today	99%	100%	98%	101%	***88%***	***91%***	87%	89%	98%	99%	87%	91%	85%	91%	71%	95%
	RV, Recycling	99%	100%	98%	100%	97%	100%	99%	100%	99%	100%	96%	100%	95%	100%	61%	84%
	900 kg , Recycling	99%	100%	98%	101%	93%	95%	95%	95%	99%	99%	93%	95%	91%	98%	52%	72%
	750 kg , Recycling	99%	100%	98%	100%	**87%**	**91%**	87%	89%	98%	98%	87%	91%	85%	91%	43%	61%
	RV, Recovery	99%	100%	99%	100%	98%	101%	99%	100%	99%	100%	96%	99%	94%	100%	82%	98%
	900 kg , Recovery	99%	100%	99%	101%	94%	97%	94%	95%	99%	99%	93%	95%	91%	98%	74%	90%
	750 kg , Recovery	99%	100%	99%	100%	**89%**	**92%**	87%	89%	98%	98%	86%	90%	85%	91%	68%	91%
Low Emissions	RV, EOL Today	92%	100%	85%	100%	98%	100%	99%	100%	96%	100%	97%	100%	95%	100%	84%	100%
	900 kg , EOL Today	93%	102%	85%	111%	93%	96%	95%	95%	93%	95%	93%	96%	91%	98%	77%	93%
	750 kg , EOL Today	91%	100%	84%	105%	88%	91%	87%	89%	88%	91%	87%	91%	85%	91%	71%	95%
	RV, Recycling	91%	99%	84%	99%	97%	100%	99%	100%	95%	100%	96%	100%	95%	100%	61%	84%
	900 kg , Recycling	93%	102%	85%	110%	93%	95%	95%	95%	93%	95%	93%	95%	91%	98%	52%	72%
	750 kg , Recycling	91%	99%	83%	104%	87%	91%	87%	89%	88%	90%	87%	91%	85%	91%	43%	61%
	RV, Recovery	91%	98%	85%	99%	98%	101%	99%	100%	96%	100%	96%	99%	94%	100%	82%	98%
	900 kg , Recovery	92%	101%	85%	111%	94%	97%	94%	95%	93%	95%	93%	95%	91%	98%	74%	90%
	750 kg , Recovery	90%	98%	84%	104%	89%	92%	87%	89%	88%	91%	86%	90%	85%	91%	68%	91%
FRV 0.5	RV, EOL Today	99%	100%	98%	100%	98%	100%	99%	100%	99%	100%	97%	100%	95%	100%	84%	100%
	900 kg , EOL Today	99%	100%	98%	101%	92%	94%	93%	94%	99%	99%	92%	94%	89%	97%	76%	92%
	750 kg , EOL Today	98%	100%	98%	100%	84%	88%	84%	85%	98%	98%	84%	88%	82%	88%	70%	93%
	RV, Recycling	99%	100%	98%	100%	97%	100%	99%	100%	99%	100%	97%	100%	95%	100%	61%	84%
	900 kg , Recycling	99%	100%	98%	101%	92%	94%	93%	94%	99%	99%	92%	94%	89%	97%	51%	71%
	750 kg , Recycling	98%	99%	98%	100%	84%	87%	84%	86%	98%	98%	84%	88%	82%	87%	42%	59%
	RV, Recovery	99%	100%	98%	100%	98%	101%	99%	100%	99%	100%	97%	100%	94%	100%	82%	98%
	900 kg , Recovery	99%	100%	98%	101%	93%	95%	93%	94%	99%	99%	92%	94%	89%	97%	74%	90%
	750 kg , Recovery	98%	99%	98%	100%	85%	89%	84%	85%	98%	98%	84%	88%	82%	87%	66%	89%
FRV 0.1	RV, EOL Today	99%	100%	98%	100%	98%	100%	99%	100%	99%	100%	97%	100%	95%	100%	84%	100%
	900 kg , EOL Today	99%	101%	99%	101%	97%	99%	98%	99%	99%	100%	96%	99%	94%	101%	79%	94%
	750 kg , EOL Today	99%	101%	99%	101%	95%	99%	96%	97%	99%	99%	95%	99%	93%	98%	75%	99%
	RV, Recycling	99%	100%	98%	98%	98%	100%	99%	100%	99%	100%	97%	100%	95%	100%	73%	100%
	900 kg , Recycling	99%	101%	99%	99%	97%	99%	98%	99%	99%	100%	97%	99%	94%	101%	64%	88%
	750 kg , Recycling	99%	101%	99%	99%	95%	99%	96%	98%	99%	99%	95%	99%	93%	99%	56%	77%
	RV, Recovery	99%	100%	98%	100%	98%	100%	99%	100%	99%	100%	97%	100%	95%	100%	84%	100%
	900 kg , Recovery	99%	101%	99%	101%	97%	99%	98%	99%	99%	100%	96%	99%	94%	101%	78%	94%
	750 kg , Recovery	99%	101%	99%	101%	96%	99%	96%	97%	99%	99%	95%	99%	93%	98%	73%	97%
No ELV CRED	RV, EOL Today	98%	100%	98%	100%	98%	100%	99%	100%	99%	100%	98%	100%	95%	100%	74%	100%
	900 kg , EOL Today	99%	104%	99%	102%	95%	104%	95%	99%	99%	100%	95%	101%	92%	104%	78%	105%
	750 kg , EOL Today	99%	105%	99%	101%	91%	100%	88%	92%	98%	99%	90%	95%	93%	111%	75%	100%
	RV, Recycling	98%	100%	98%	100%	98%	100%	99%	100%	99%	100%	98%	100%	95%	100%	74%	100%
	900 kg , Recycling	99%	104%	99%	102%	95%	104%	95%	99%	99%	100%	95%	101%	92%	104%	78%	105%
	750 kg , Recycling	99%	105%	99%	101%	91%	100%	89%	92%	98%	99%	90%	95%	93%	111%	75%	100%
	RV, Recovery	98%	100%	98%	100%	98%	100%	99%	100%	99%	100%	98%	100%	95%	100%	74%	100%
	900 kg , Recovery	99%	104%	99%	102%	95%	104%	95%	99%	99%	100%	95%	101%	92%	104%	78%	105%
	750 kg , Recovery	99%	105%	99%	102%	91%	101%	88%	92%	98%	99%	90%	95%	93%	111%	75%	100%
N.O.	RV, EOL Today	99%	100%	98%	100%	98%	100%	99%	100%	99%	100%	97%	100%	95%	100%	85%	100%
	900 kg , EOL Today	99%	100%	98%	101%	93%	96%	95%	95%	99%	99%	93%	96%	91%	98%	79%	86%
	750 kg , EOL Today	99%	100%	98%	101%	88%	91%	87%	89%	98%	99%	87%	91%	85%	91%	70%	79%
	RV, Recycling	99%	100%	98%	100%	97%	100%	99%	100%	99%	100%	96%	100%	95%	100%	85%	100%
	900 kg , Recycling	99%	100%	98%	101%	93%	95%	95%	95%	99%	99%	93%	95%	91%	98%	79%	86%
	750 kg , Recycling	99%	100%	98%	100%	87%	91%	87%	89%	98%	98%	87%	91%	85%	91%	71%	80%
	RV, Recovery	99%	100%	99%	100%	98%	101%	99%	100%	99%	100%	96%	99%	94%	100%	85%	100%
	900 kg , Recovery	99%	100%	99%	101%	94%	97%	94%	95%	99%	99%	93%	95%	91%	98%	79%	86%
	750 kg , Recovery	98%	99%	98%	101%	88%	92%	87%	89%	98%	99%	87%	91%	85%	91%	70%	79%

N.O. = No overburden